Effects of Brown Midrib Corn Silage on the Energy Balance of Dairy Cattle[1]

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ABSTRACT

Effects of genotype and level of intake on net energy for lactation values of corn silage were evaluated by indirect calorimetry in two experiments using lactating and dry, nonpregnant dairy cows. In experiment 1, six multiparous Holstein cows in early lactation were fed experimental diets containing either brown midrib (bm3) or isogenic normal corn silage. Dietary treatments were isogenic and bm3 diets fed ad libitum, and the bm3 diets restricted-fed. Dry matter (DM) intake was 2.4 kg/d greater for cows fed the bm3 diet ad libitum compared with cows fed the isogenic diet. Apparent digestibilities of DM, organic matter, neutral detergent fiber, and acid detergent fiber were greater for cows restricted-fed bm3 than the isogenic diet. In experiment 2, six dry, nonpregnant Holstein cows were fed maintenance diets containing either bm3 or isogenic corn silage. Apparent digestibilities of DM, organic matter, neutral detergent fiber, and acid detergent fiber were greater for cows fed bm3 compared with isogenic corn silage. Digestible energy and metabolizable energy were greater for maintenance diets containing bm3 compared with isogenic corn silage, respectively. These data indicate increased milk production seen in other studies is a result of increased DMI rather than an increase in energy efficiency. Increased organic matter digestibility of bm3 corn silage resulted in greater digestible energy and metabolizable energy values in cows fed at maintenance energy intake. However, calculated net energy for lactation values of bm3 and isogenic corn silages were similar at both productive and maintenance levels of feeding.
(**Key words:** brown midrib corn silage, energy balance)

Abbreviation key: bm3 = brown midrib 3, **BMR** = brown midrib diet fed ad libitum, **BMRM** = brown midrib corn silage diet fed at a maintenance level of intake, **BMRR** = brown midrib diet restricted fed, **DE** = digestible energy, **EE** = ether extract, **GE** = gross energy, **HP** = heat production, **ISO** = isogenic corn silage diet fed ad libitum, **ISOM** = isogenic corn silage diet fed at a maintenance level of intake, **ME** = metabolizable energy, **NFC** = nonfiber carbohydrates, **UE** = urinary energy.

INTRODUCTION

Brown midrib mutant genotypes of corn were identified at the University of Minnesota in 1924 (Jorgenson, 1931). Corn varieties containing the mutant brown midrib gene (**bm3**) have lower lignin content (Cherney et al., 1991) and thus higher digestibility of the NDF and ADF fiber fractions. In vitro (Barnes et al., 1971; Lechtenberg, et al., 1972, 1974) and in vivo (Muller et al., 1972; Stallings et al., 1982) experiments have demonstrated the effect of bm3 on fiber digestibility. Feeding experiments with brown midrib corn silage in dairy cattle consistently have shown increases in DMI (Block et al., 1981; Frenchick et al., 1976; Keith et al., 1979; Oba and Allen, 1999; Rook et al., 1977; Sommerfeldt et al., 1979), presumably by reducing rumen and digestive tract fill due to increased fiber digestibility (Allen, 1996; Dado and Allen, 1995; Mertens, 1987).

Accurate estimation of forage energy content is critical to the application of brown midrib varieties, and for that matter, any improved forage variety in dairy cattle feeding. Typically, energy values of forages are estimated based on their NDF or ADF content (Conrad et al., 1984). Some equations that are currently used to estimate energy values by feed analysis laboratories

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would underestimate digestibilities of brown midrib corn silage because they do not account for the decrease in fiber lignification and the increases in fiber digestibility. More recently, Weiss et al. (1992) described a model for estimating digestibility that incorporated the effect of lignification on digestibility of fiber and potentially could overcome the limitations of previous equations to estimate digestibility. Since the digestibility of the fiber portion of brown midrib varieties is so much greater than traditional genotypes, commonly used equations for estimating energy values would likely be inaccurate when applied to forage analysis of brown midrib corn silage.

Typically, dairy cattle rations are fed as mixed diets composed of several individual feedstuffs. Determining the energy value of a single feedstuff with the NE_L system is complicated when the feedstuff is fed as part of a mixed ration. Variation in energy values are created by differing physical and chemical properties among individual feedstuffs (Moe and Tyrrell, 1973), effects of level of intake on nutrient digestibility (Tyrrell and Moe, 1975), and interactions among feedstuffs fed as part of a mixed diet (Moe et al., 1972). For example, current NRC requirements assume a 4% decrease in digestibility for each multiple of intake above maintenance (NRC, 1989). Therefore, digestibilities and energy values for lactating cows have been adjusted, assuming 3× maintenance feeding. It is not clear whether energy values at feeding above 3× maintenance should be adjusted further (Tyrrell and Moe, 1975). However, cows fed diets composed of primarily one feedstuff at maintenance intake, provide reference energy values to which energy values for lactating dairy cows could be compared.

To take advantage of the potential use of brown midrib corn silage in dairy cattle diets, accurate energy values are needed for proper ration formulation. The objective of this experiment was to determine the energy value of a brown midrib corn silage in early lactation dairy cows fed at high feed intake and in dry cows fed at maintenance.

MATERIALS AND METHODS

Corn Silage

Corn hybrid varieties used in these studies for silage production (bm3, FullTime F657 and isogenic, 6208 FQ hybrid; Cargill Hybrid Seeds, Minneapolis, MN), were planted in a split field on May 24 and harvested on September 1 and 2, 1998. Because of differences in plant fragility, corn plants were chopped using theoretical lengths of 1.6 cm and 1.9 cm for isogenic and bm3, respectively, and ensiled in separate 5.5- × 21.3-m concrete stave upright silos. Particle size distribution of the green chop was determined by the procedure described by Lammers et al. (1996) and was similar for both corn varieties, with 34 and 46% of the total green chop material being retained on a 1.9- and 0.8-cm screen, respectively. Beginning 2 mo after the ensiling process and throughout both experiments, a minimum of 200-kg of silage was removed daily from each silo for ration preparation and to prevent spoilage. Chemical compositions of the isogenic and bm3 corn silage used in the experimental diets are presented in Table 1.

Animals

Lactating and dry, nonpregnant Holstein cows were obtained from the research dairy herds at Central Maryland Research and Education Center and Agricultural Research Services facilities at Beltsville, MD. Cows were housed in a tie-stall (1.8- × 1.5-m stall dimensions) barn at an ambient temperature of 16°C (65% relative humidity), with a 16-h light cycle and had continuous access to water. This environment was maintained to duplicate the environment of the respiration calorimeters. Cows were adapted to the tie-stall barn a minimum of 3 wk prior to initiation of experimental treatments. During this period, cows were transitioned from herd diets to experimental corn silage-based diets, containing isogenic silage, by incrementally increasing the percentage of experimental diets in the daily ration over 5 d. Cows were fed twice (0830 and 2030 h) daily and feed refusals and rectal temperatures were recorded prior to the a.m. feeding. Lactating cows were milked twice (0630 and 1830 h) daily and milk weights were recorded. Except when in the chambers, cows were exercised (1 h) daily and weighed twice weekly. All procedures involving the cows were approved by the Beltsville Agricultural Research Center Institutional Animal Care and Use Committee (protocol # 98-021).

Table 1. Chemical composition (% of DM) of corn silage used in lactating cow (Experiment 1) and dry, nonpregnant cow (Experiment 2) diets.

Item	Isogenic	bm3[1]
DM, %	38.1	39.5
Gross energy, Mcal/kg of DM	4.56	4.50
CP	8.60	8.26
NDF	46.2	43.8
ADF	28.3	26.3
Lignin	3.60	2.47
Nonfiber carbohydrates	57.6	59.1
Ether extract	3.04	2.92
C	47.2	46.6
Ash	4.82	4.62

[1]Brown midrib 3 mutant.

Table 2. Ingredient composition (% of DM) of experimental diets consumed by lactating cows (Experiment 1) and dry, nonpregnant cows (Experiment 2).[1]

Item	Lactating	Dry
Corn silage	60.0	98.0
Soybean meal, 48% CP	17.7	. . .
Ground corn	13.1	. . .
Soypass[2]	5.00	. . .
Megalac[3]	1.04	. . .
Urea	. . .	1.18
Dicalcium phosphate	0.96	0.12
Sodium bicarbonate	0.88	. . .
Limestone	0.56	0.09
Trace-mineralized salt	0.49	0.45
Dynamate[4]	0.19	0.05
Magnesium oxide	0.07	. . .
Vitamin E[5]	0.06	0.04
Vitamin A[6]	0.03	0.05
Vitamin D[7]	0.01	0.01

[1]All experimental diets for lactating cows used the same concentrate mix.

[2]Ligno Tech, Ft. Wayne, IN.

[3]Church and Dwight Co., Princeton, NJ.

[4]Pitman Moore, Inc., Mundelein, IL.

[5]Vitamin E premix = 44 IU/g.

[6]Vitamin A premix = 10,000 IU/g.

[7]Vitamin D premix = 15,000 IU/g.

Experiment 1

Design and diets. Six multiparous cows were assigned randomly to replicated 3×3 Latin squares with each square balanced for carryover effects. Dietary treatments were a TMR containing either isogenic (**ISO**) or bm3 corn silage fed ad libitum (**BMR**) or bm3 limit fed (**BMRR**) to approximate ad libitum DMI of ISO. Before the initial experimental period, cows were placed on a 14-d preliminary trial to establish ad libitum DMI of ISO. Daily DMI for each cow was averaged over the last 5 d and subsequently used as the restricted intake for that cow while on the BMRR treatment during the experimental period.

Experimental diets (Table 2) consisted of 60% corn silage and 40% concentrate (DM basis), differing only in the corn silage variety used. Diets were formulated to meet or exceed the requirements for RDP, RUP, NDF, ADF, Ca, and P for lactating cows (NRC, 1989). Total mixed rations were prepared each day (Calan Data Ranger; American Calan Inc., Northwood, NH) and stored (4°C) until feeding. Daily samples of silage and grain mix were collected and DM content (100°C) was determined. Average DM was calculated weekly and used to adjust diets and the amount of feed offered the following week.

Energy and nitrogen balance. Experimental periods were 28 d. During the initial 14 d, the amount of feed offered was adjusted twice weekly to achieve 10%

orts, with the exception of limit fed cows on the BMRR treatment. Following this adjustment, the amount of feed offered was set on d 15 and held constant throughout the remainder of the period. Heart rate, rectal temperature, and BW were determined daily during wk 3. Heart rate and rectal temperature measurements continued during energy and N balance measurements to monitor animal health and well being. The last 7 d of each period, cows were placed into the Beltsville open-circuit calorimeters for the determination of energy and N balance (Flatt et al., 1958). Before they entered the chamber, Foley catheters (Bardex Open Funnel number 24 French, 75-cc balloon; C.R. Bard, Inc., Covington, GA) were inserted into the bladder of each cow for urine collection into preacidified (800 ml of 25% phosphoric acid) containers. Sampling of TMR for energy balance measurements began on d 19, accounting for the time associated with the rate of passage of digesta in dairy cattle. Orts sampling began on d 20. Subsamples of corn silage, concentrate mix, TMR, orts, feces, and urine were taken daily, stored (–20°C), and composited at the end of each period. Daily aliquots of corn silage, concentrate mix, TMR, orts, and feces were analyzed for DM by drying to a constant weight at 100°C. Daily fecal collections were mixed for 7 min (model L-800; The Hobart Manufacturing Co., Troy, OH) before sampling. Subsamples of corn silage, TMR, orts, and fecal samples were chopped for 3-min in a vertical cutter-mixer (model VCN-40; The Hobart Manufacturing Co., Troy, OH), composited, and ground with dry ice (1-mm screen; model ZM-1; Brinkman Instruments Inc., Westbury, NY). A portion of the freeze-ground material was dried (55°C) for fiber analyses. The remaining freeze-ground sample was stored (4°C) for 24 h to allow the CO_2 to dissipate and was sampled for analysis or stored (–20°C) as a reserve sample. Milk samples (0.24 L per milking) were preserved with 26.5% potassium dichromate tablets and stored (4°C). Upon the completion of the digestion trial, milk samples were tempered (40°C) for 2 h and composited using a set proportion of the daily milk weight. Composited milk samples were analyzed for fat, CP, and SNF by infrared analysis (Environmental Systems Services, Ltd., College Park, MD). At the end of each period, cows were removed from the chambers and solid material remaining in the chambers was separated into feed, feces, and hair and combined with the appropriate sample. Water used to facilitate removal of dried feces in the chamber was collected, homogenized, and analyzed for N content.

Chambers were sealed on d 22 and data acquisition (KDAC500/I; Keithley Instruments Inc., Cleveland, OH) began the following day. On d 24 to 26, 24-h measurements of respiratory exchange and methane production in the open-circuit calorimetry chambers were

recorded. Gases from the chambers were continuously collected into spirometers to provide a 24-h composite and analyzed for CO_2, O_2, and CH_4. Heat production (**HP**) was calculated from CO_2 production and O_2 consumption corrected for CH_4 production and urinary N excretion (Brouwer, 1965).

Chemical analyses. Composite corn silage, TMR, orts, and fecal samples were dried (55°C) and ash content determined (AOAC, 1975). Wet composite samples of corn silage, TMR, orts, feces, urine, and milk were analyzed for N and C content (LECO C/N 2000; model 601-900-000; LECO Corporation, St. Joseph, MI), and gross energy (**GE**) content by combustion in an adiabatic bomb calorimeter (model 1241; Parr Instrument Co., Moline, IL) with the aid of a polyethylene primer bag of known weight and energy content. Urine and milk samples were evaporated to near dryness at 40°C in a forced-air oven before combustion in the bomb calorimeter. Fiber analysis was conducted using the detergent analysis system (Goering and Van Soest, 1970) adapted for the ANKOM[200] fiber unit (ANKOM Technology Corporation, Fairport, NY). The NDF procedure was modified by the addition of heat-stable amylase (Sigma Chemical, St. Louis, MO) to all samples during analysis. Lignin content was analyzed using a 72% sulfuric acid digestion (Goering and Van Soest, 1970). Dried (55°C) composite corn silage samples were analyzed for ether extract (**EE**; AOAC, 1975) and nonfiber carbohydrates (**NFC**) were calculated using the formula: NFC = DM − (NDF + CP + EE + ash) (Mertens, 1992). Carbon, energy, and N balances were calculated according to Flatt and Tabler (1961) and Moe et al. (1972) using a program developed for SAS (1988).

Experiment 2

Six dry, nonpregnant Holstein cows were randomly assigned to a single reversal design to test for the effects of corn silage variety (isogenic normal vs. bm3) on energy and N balances of the cows. Cows were fed either a TMR containing isogenic (**ISOM**) or bm3 (**BMRM**) corn silage at 0.141 Mcal metabolizable energy (**ME**)/ kg of $BW^{0.75}$ which approximated maintenance energy intake of dry, nonpregnant cows (NRC, 1989). Experimental diets (Table 2) consisted of 98% corn silage and 2% concentrate (DM basis), differing only in the corn silage variety fed. Diets were formulated to meet or exceed the requirements for CP, NDF, ADF, Ca, and P for dry, nonpregnant dairy cows (NRC, 1989). Diets were adjusted weekly to account for changes in DM. Experimental periods were 21 d. Similar to experiment 1, cows were adapted to the appropriate diet on d 1 to 7, and the amount of feed offered was adjusted (d 8)

based on BW and was maintained throughout the remainder of the period.

Measurements of energy and N balance and chemical analyses were conducted according to procedures described in experiment 1. In addition to corn silage, dried (55°C) TMR and fecal composite samples were analyzed for EE and NFC. The TDN value of each diet was calculated using the formula: TDN = (digestible OM − digestible EE) + (digestible EE × 2.25); where digestible OM and EE are expressed as a percentage of total diet.

Statistical Analysis and Calculations

All statistical analyses were performed using the general linear models procedure in SAS (1988). The statistical model for experiment 1 included square, treatment, period, and animal within square. Effects of genotype (BMRR vs. ISO) and level of intake (BMRR vs. BMR) were determined by orthogonal contrasts (Steel and Torrie, 1980). The statistical model for experiment 2 included treatment, animal, and period. Analyses of variance for chemical composition of the TMR were performed using square, treatment, and period and treatment and period in the models for experiments 1 and 2, respectively. Effects of independent variables were considered significant at $P < 0.05$ for both experiments.

Measured NE_L values were calculated by adjusting milk energy for tissue gain and loss, excess N intake, pregnancy, and maintenance energy requirements (Moe et al., 1972). Maintenance energy requirements for lactating cows was assumed to be 73 kcal of NE_L/ $kg^{0.75}$ of live weight, based on previous measurements using fasting cows in the Beltsville calorimetry chambers (Tyrrell and Moe, 1972). Calculated energy values for isogenic and bm3 corn silage, within dietary treatments in experiment 1, were determined by subtracting an adjusted NRC (1989) energy value of the concentrate portion from the energy value of the diets. Energy value of the concentrate portion of the diet was adjusted for 4× maintenance energy intake by reducing the NRC (1989) estimated NE_L value by 4%. The following equation was used to estimate energy values of corn silage:

$$E_{CS} = (E_{UD} − (\Sigma (E_C \times F_C)))/F_{CS}$$

where: E_{CS} represents the energy value of the corn silage in the diet, E_{UD} is the energy value of the diet, E_C is the energy value of the concentrate in the diet, F_C is the fraction of concentrate in the diet, and F_{CS} is the fraction of corn silage in the diet.

Table 3. Chemical composition (% of DM) of experimental diets consumed by lactating (experiment 1) and dry, nonpregnant cows (experiment 2).

Item	Lactating cows				Dry cows			
	Iso[1]	Bm3[2]	SEM[3]	Effects[4]	Iso[1]	Bm3[2]	SEM[3]	Effects[4]
DM, %	51.4	52.4	0.44	. . .	38.4	40.4	0.19	0.0001
Gross energy,								
Mcal/kg of DM	4.46	4.46	0.01	. . .	4.49	4.49	0.01	. . .
CP	19.7	19.7	0.20	. . .	12.6	12.4	0.13	. . .
NDF	32.0	31.3	0.50	. . .	46.3	45.0	0.27	0.008
ADF	18.7	17.4	0.27	0.01	29.0	27.4	0.32	0.005
Lignin	1.78	1.11	0.07	0.0003	2.69	1.50	0.19	0.002
Nonfiber carbohydrates	. . .	. . .	. . .		53.90	55.72	0.27	0.0009
Ether extract	. . .	. . .	. . .		3.03	2.78	0.12	. . .
C	46.2	46.1	0.10	. . .	46.9	46.7	0.08	0.04
Ash	7.56	7.38	0.06	0.08	5.17	5.06	0.09	. . .

[1]Iso = Diet containing isogenic corn silage.

[2]Bm3 = Diet containing bm3 corn silage.

[3]n = 6.

[4]Probability of larger F statistic; $P > 0.10$, not shown.

RESULTS

Experiment 1

The chemical composition of diets containing isogenic or bm3 silage fed to lactating cows are presented in Table 3. Dry matter, GE, CP, NDF, and C were similar for both diets. However, ADF ($P = 0.01$) and lignin ($P = 0.0003$) content were lower, and ash content tended ($P = 0.08$) to be lower, for the BMR diet compared with the ISO diet.

The mean age (43 ± 4 mo), DIM (155 ± 23 d), and stage of gestation (79 ± 44 d) were similar ($P > 0.10$) across treatments (data not shown). Milk yield and composition (Table 4) did not differ ($P > 0.10$) among dietary treatments with the exception of a lower ($P = 0.04$) fat percentage, and a trend for higher ($P = 0.07$) protein yield, for cows fed BMR compared with those fed BMRR.

Body weight was lower for cows fed BMRR compared with cows fed either ISO ($P = 0.002$) or BMR ($P = 0.0003$; Table 5). Dry matter intake was similar ($P > 0.10$) for cows fed ISO compared with those fed BMRR; however, DMI was greater ($P = 0.0005$) for BMR versus BMRR. Apparent digestibilities of DM ($P = 0.003$), OM ($P = 0.002$), NDF ($P = 0.0001$), ADF ($P = 0.004$), hemicellulose ($P = 0.003$), cellulose ($P = 0.0001$), and C ($P = 0.02$) were higher for BMRR than ISO. However, apparent CP digestibility ($P = 0.03$) was lower for BMRR compared with ISO. Apparent digestibilities were generally unaffected by level of intake of bm3 corn silage diets (BMR vs. BMRR), with the exception of a decrease in apparent NDF ($P = 0.01$) and cellulose ($P = 0.006$) digestibility for BMR versus BMRR.

Intake of GE, digestible energy (**DE**), and ME were similar ($P > 0.10$) for cows fed BMRR and ISO (Table

Table 4. Milk yield and composition in lactating cows during balance trials (Experiment 1).

Item	Lactating cows					
					Effect[5]	
	ISO[1]	BMRR[2]	BMR[3]	SEM[4]	Genotype	Intake
Milk, kg/d	32.3	33.0	35.4	1.03	. . .	. . .
3.5% FCM, kg/d	31.3	31.8	33.5	0.89	. . .	. . .
Protein, %	3.20	3.24	3.32	0.05	. . .	. . .
Fat, %	3.93	3.92	3.76	0.05	. . .	0.04
SNF, %	8.64	8.70	8.84	0.07	. . .	. . .
Protein, g/d	1023	1043	1161	39	. . .	0.07
Fat, g/d	1221	1240	1289	35	. . .	. . .

[1]ISO = Isogenic corn silage diet fed ad libitum.

[2]BMRR = bm3 corn silage diet restricted fed.

[3]BMR = bm3 corn silage diet fed ad libitum.

[4]n = 6.

[5]Probability of larger F statistic; $P > 0.10$, not shown. Genotype = ISO vs. BMRR, Intake = BMRR vs. BMR.

Table 5. Body weight, DMI, and apparent digestibilities of dietary components in lactating (experiment 1) and dry, nonpregnant cows (experiment 2).

	Lactating cows						Dry cows			
					Effects[5,6]					Effects[5,9]
Item	ISO[1]	BMRR[2]	BMR[3]	SEM[4]	Genotype	Intake	ISOM[7]	BMRM[8]	SEM[4]	Genotype
BW, kg	616	598	621	3	0.002	0.0003	620	613	36	. . .
DMI, kg/d	22.8	22.3	25.2	0.36	. . .	0.0005	6.59	6.53	0.29	. . .
Apparent digestibility, %										
DM	68.5	69.7	69.8	0.19	0.003	. . .	71.1	74.4	0.64	0.005
OM	70.0	71.1	71.3	0.17	0.002	. . .	72.8	76.2	0.17	0.005
CP	71.8	69.7	69.2	0.68	0.03	. . .	69.1	65.8	0.76	0.01
NDF	48.8	58.3	55.8	0.52	0.0001	0.01	62.4	71.6	0.92	0.0001
ADF	47.8	56.3	55.0	1.48	0.004	. . .	59.1	69.0	1.69	0.003
Hemicellulose	50.1	60.6	56.7	1.77	0.003	. . .	67.8	75.5	1.89	0.02
Cellulose	56.5	64.1	61.3	0.55	0.0001	0.006	72.4	80.9	1.24	0.0009
Nonfiber carbohydrates	. . .	. . .	. . .	. . .			78.8	81.4	0.75	0.04
Ether extract	. . .	. . .	. . .	. . .			81.5	71.6	1.36	0.0006
C	69.1	69.8	70.0	0.17	0.02	. . .	71.6	74.4	0.65	0.01

[1]ISO = Isogenic corn silage diet fed ad libitum.

[2]BMRR = bm3 corn silage diet restricted fed.

[3]BMR = bm3 corn silage diet fed ad libitum.

[4]n =6.

[5]Probability of larger F statistics; $P > 0.10$, not shown.

[6]Genotype = ISO vs. BMRR, Intake = BMRR vs. BMR.

[7]ISOM = Isogenic corn silage diet fed at maintenance.

[8]BMRM = bm3 corn silage fed at maintenance.

[9]Genotype = ISOM vs. BMRM.

6). Urinary energy (**UE**) ($P = 0.007$), UE as a percentage of intake energy ($P = 0.02$), and methane energy ($P = 0.06$) were lower in cows fed BMRR compared with those fed ISO. However, heat production, milk energy, and tissue energy were similar ($P > 0.10$) for cows fed BMRR and ISO. Intake of GE ($P = 0.0003$), DE ($P = 0.0008$), and ME ($P = 0.001$), and energy losses associated with urine ($P = 0.03$) and methane ($P = 0.01$) were higher for cows fed BMR versus cows fed BMRR. However, as a percentage of intake energy, methane energy loss was lower ($P = 0.03$) for cows fed BMR versus BMRR. Heat production was higher ($P = 0.0002$) for cows fed BMR compared with those fed BMRR. However, heat production, as a function of intake energy, tended to be lower ($P = 0.07$) for cows fed BMR versus BMRR. Total energy balance, i.e., sum of milk and retained tissue energy, was greater ($P = 0.008$) for cows fed BMR compared with those fed BMRR as a result of a numerical increase in milk energy (24.6 vs. 23.0 Mcal/d) and an increase ($P = 0.03$) in tissue energy balance. Additionally, tissue energy balance, as a function of ME, was greater ($P = 0.05$) for cows fed BMR versus those fed BMRR.

Digested N tended to be greater ($P = 0.07$), and urinary N was greater ($P = 0.0006$) for cows fed ISO versus BMRR (Table 7). Nitrogen intake, fecal N and milk N output, and total N balance were not different ($P > 0.10$) between ISO and BMRR treatments. Cows fed BMR had greater N intake ($P = 0.0005$), fecal N output ($P = 0.0004$), digested N ($P = 0.004$), urinary N output ($P = 0.0005$), and milk N output ($P = 0.04$) compared with cows fed BMRR. However, retained N was similar ($P > 0.10$) for BMR and BMRR.

Dietary GE, DE, ME, and NE$_L$ values were similar ($P > 0.10$) across treatment and averaged 4.46, 3.11, 2.70, and 1.61 Mcal/kg of dietary DM, respectively (Table 8). With estimated energy values (NRC, 1989) for the concentrate portion of the diets, calculated energy values for the corn silage components (Table 9) were 3.10 Mcal of DE/kg of DM, 2.58 Mcal of ME/kg of DM, and 1.43 Mcal of NE$_I$/kg of DM for isogenic corn silage and averaged 3.12 Mcal of DE/kg of DM, 2.68 Mcal of ME/kg of DM, and 1.49 Mcal of NE$_I$/kg of DM for bm3 corn silage (average of BMR and BMRR).

Experiment 2

The chemical composition of ISOM and BMRM diets fed to dry, nonpregnant cows are presented in Table 3. Dry matter ($P = 0.0001$) and NFC concentrations ($P = 0.0009$) were greater for BMRM than ISOM. However, NDF ($P = 0.008$), ADF ($P = 0.005$), lignin ($P = 0.002$), and C ($P = 0.04$) contents were lower for BMRM com-

pared with ISOM. Gross energy, CP, EE, and ash concentrations were similar ($P > 0.10$) for BMRM and ISOM diets.

Body weight and DMI were similar ($P > 0.10$) for cows fed BMRM and ISOM (Table 5). Apparent digestibilities of DM ($P = 0.005$), OM ($P = 0.005$), NFC ($P = 0.04$), and C ($P = 0.01$) were greater for BMRM than ISOM. Additionally, BMRM had greater apparent digestibilities of NDF ($P = 0.0001$), ADF ($P = 0.003$), hemicellulose ($P = 0.02$), and cellulose ($P = 0.0009$) compared with ISOM. However, apparent digestibilities of EE ($P = 0.0006$) and CP ($P = 0.01$) were lower for BMRM compared with ISOM.

Intake of GE, DE, ME, and losses associated with urine and methane were not affected ($P > 0.10$) by treatment (Table 6). As a proportion of intake energy, DE ($P = 0.02$) and ME ($P = 0.004$) were greater for cows fed BMRM compared with those fed ISOM. Conversely, UE as a proportion of intake energy, tended to be lower ($P = 0.07$) for cows fed BMRM versus those fed ISOM. Heat production and tissue energy balance were unaffected ($P > 0.10$) by treatment.

Intake N, fecal N, digested N, urinary N, and retained N in cows fed maintenance levels of intake were not affected ($P > 0.10$) by dietary treatment (Table 7). Retained N averaged 3.5% of the digested N and was not different between treatments.

Gross energy was similar ($P > 0.10$) for ISOM and BMRM (Table 8). Total digestible nutrients ($P = 0.03$), DE ($P = 0.02$), and ME ($P = 0.004$) were greater for BMRM compared with ISOM, while NE_L was unaffected ($P > 0.10$) by diet.

Table 6. Energy balance in lactating (experiment 1) and dry, nonpregnant cows (experiment 2).

| | Lactating cows | | | | | | Dry cows | | | |
| | | | | | Effects[5,6] | | | | | Effects[5,9] |
Item	ISO[1]	BMRR[2]	BMR[3]	SEM[4]	Genotype	Intake	ISOM[7]	BMRM[8]	SEM[4]	Genotype
Intake energy, Mcal/d	101.6	99.3	112.5	1.5	. . .	0.0003	29.6	29.3	1.3	. . .
Digestible energy										
Mcal/d	70.5	69.1	78.7	1.3	. . .	0.0008	21.1	21.7	1.0	. . .
% of intake energy	69.4	69.6	70.0	0.5	. . .	. . .	71.2	74.0	0.7	0.02
Urine energy										
Mcal/d	4.0	3.4	3.9	0.1	0.007	0.03	1.3	1.1	0.1	. . .
% of intake energy	3.9	3.5	3.4	0.1	0.02	. . .	4.2	3.9	0.1	0.07
Methane energy										
Mcal/d	5.8	5.5	6.0	0.1	0.06	0.01	2.5	2.5	0.1	. . .
% of intake energy	5.8	5.6	5.3	0.1	. . .	0.03	8.6	8.4	0.2	. . .
ME[10]										
Mcal/d	60.7	60.1	68.9	1.2	. . .	0.001	17.3	18.0	0.8	. . .
% of intake energy	59.7	60.6	61.2	0.5	. . .	. . .	58.4	61.6	0.6	0.004
Heat production										
Mcal/d	34.6	34.1	37.3	0.4	. . .	0.0002	17.2	17.0	0.6	. . .
% of intake energy	34.1	34.3	33.2	0.4	. . .	0.07	58.2	58.3	1.7	. . .
% of ME	57.3	56.7	54.2	1.0	. . .	. . .	99.6	94.6	2.8	. . .
Total energy balance										
Mcal/d	26.1	26.0	31.6	1.1	. . .	0.008	. . .	. . .	. . .	
Milk energy										
Mcal/d	22.7	23.0	24.6	0.7	. . .	. . .	. . .	. . .	. . .	
% of ME	37.5	38.3	35.6	1.0	. . .	. . .	. . .	. . .	. . .	
Tissue energy balance										
Mcal/d	3.3	3.0	7.0	1.0	. . .	0.03	0.1	1.0	0.5	. . .
% of ME	6.1	5.0	10.1	1.5	. . .	0.05	0.4	5.4	2.8	. . .

[1]ISO = Isogenic corn silage diet fed ad libitum.

[2]BMRR = bm3 corn silage diet restricted fed.

[3]BMR = bm3 corn silage diet fed ad libitum.

[4]n = 6.

[5]Probability of larger F statistic; $P > 0.10$, not shown.

[6]Genotype = ISO vs. BMRR, Intake = BMRR vs. BMR.

[7]ISOM = Isogenic corn silage diet fed at maintenance.

[8]BMRM = bm3 corn silage fed at maintenance.

[9]Genotype = ISOM vs. BMRM.

[10]Metabolizable energy.

Table 7. Nitrogen balance (g/d) in lactating (experiment 1) and dry, nonpregnant cows (experiment 2).

	Lactating cows				Effects[5,6]		Dry cows			Effects[5,9]
Item	ISO[1]	BMRR[2]	BMR[3]	SEM[4]	Genotype	Intake	ISOM[7]	BMRM[8]	SEM[4]	Genotype
Intake	718	683	794	14	. . .	0.0005	133	129	5	. . .
Fecal	203	211	241	4	. . .	0.0004	41	44	2	. . .
Digested	515	472	554	14	0.07	0.004	92	85	4	. . .
Urine	319	269	322	7	0.0006	0.0005	90	80	4	. . .
Milk	163	163	183	6	. . .	0.04	. . .	. . .	. . .	
Hair	0.05	0.05	0.09	0.02	. . .	0.08	0.08	0.07	0.02	. . .
Wash water	0.85	0.67	0.87	0.18	. . .	. . .	0.20	0.28	0.05	. . .
Retained	32	39	48	11	. . .	. . .	1.47	4.66	2.03	. . .

[1]ISO = Isogenic corn silage diet fed ad libitum.

[2]BMRR = bm3 corn silage diet restricted fed.

[3]BMR = bm3 corn silage diet fed ad libitum.

[4]n = 6.

[5]Probability of larger F statistic; $P > 0.10$, not shown.

[6]Genotype = ISO vs. BMRR, Intake = BMRR vs. BMR.

[7]ISOM = Isogenic corn silage diet fed at maintenance.

[8]BMRM = bm3 corn silage fed at maintenance.

[9]Genotype = ISOM vs. BMRM.

DISCUSSION

In cows fed the BMR treatment, DMI increased by 2.6 kg/d, compared with BMRR and ISO treatments (Table 6). Oba and Allen (1999) and Block (1981) also observed similar increases in DMI. However, the effects of bm3 corn silage on DMI in other feeding experiments with lactating dairy cows were less consistent (Frenchick et al., 1976; Keith et al., 1979; Rook et al., 1977; Sommerfeldt et al., 1979). These studies were conducted with cows in late lactation where energy requirements would be lower (Frenchick et al., 1976; Keith et al., 1979). In one experiment in which there were no effects of bm3 corn silage on intake, cows were fed relatively low concentrations of protein (Sommerfeldt et al., 1979). Feeding bm3 corn silage appears to allow greater DMI when fed to dairy cows in early to midlactation. Dry matter intake of cows, especially in early lactation, is limited by rumen fill (Allen, 1996; Dado and Allen, 1995; Mertens, 1987), thereby limiting

Table 8. Energy values (Mcal/kg of dietary DM) of diets containing 60% corn silage and 40% concentrate (experiment 1) and diets containing 98% corn silage fed at maintenance (experiment 2).

	Lactating cows				Effects[5,6]		Dry cows			Effects[5,9]
Item	ISO[1]	BMRR[2]	BMR[3]	SEM[4]	Genotype	Intake	ISOM[7]	BMRM[8]	SEM[4]	Genotype
TDN, %	. . .	. . .	. . .	. . .			72.1	74.8	0.7	0.03
Gross energy	4.46	4.45	4.46	0.01	. . .	. . .	4.49	4.49	0.01	. . .
Digestible energy	3.10	3.10	3.12	0.03	. . .	. . .	3.20	3.32	0.03	0.02
Metabolizable energy	2.66	2.70	2.73	0.03	. . .	. . .	2.62	2.77	0.03	0.004
NE_L[10]	1.59	1.60	1.64	0.04	. . .	. . .	1.42	1.54	0.06	. . .

[1]ISO = Isogenic corn sialge diet fed ad libitum.

[2]BMRR = bm3 corn silage diet restricted fed.

[3]BMR = bm3 corn silage diet fed ad libitum.

[4]n = 6.

[5]Probability of larger F statistic; $P > 0.10$, not shown.

[6]Genotype = ISO vs. BMRR, Intake = BMRR vs. BMR.

[7]ISOM = Isogenic corn silage diet fed at maintenance.

[8]BMRM = bm3 corn silage fed at maintenance.

[9]Genotype = ISOM vs. BMRM.

[10]Calculated by adjusting milk energy (experiment 1) or maintenance energy (experiment 2) for tissue gain and loss, excess N intake, and pregnancy (experiment 1).

Table 9. Calculated energy values at 4× maintenance energy intake (Mcal/kg of dietary DM) of corn silage.[1]

Item	ISO[2]	BMRR[3]	BMR[4]
Digestible energy	3.10	3.10	3.13
Metabolizable energy	2.58	2.65	2.70
NE$_L$	1.43	1.45	1.52

[1]Energy values for isogenic and bm3 corn silage within dietary treatments in Experiment 1, were estimated by subtracting estimated NRC (1989) energy values of the concentrate from the energy values of the entire diet.

[2]ISO = Isogenic corn silage diet fed ad libitum.

[3]BMRR = bm3 corn silage diet restricted fed.

[4]BMR = bm3 corn silage diet fed ad libitum.

energy intake. Possibly, the intake effect of bm3 corn silage is through reduction in digestive tract fill limitations.

Accurate determination of corn silage digestibility is important in evaluating the value of bm3 corn silage as a forage source in dairy cow diets. In experiment 2, dry cows were fed a diet composed primarily of corn silage at maintenance energy intake. This provides baseline digestibility data that is not confounded by other dietary energy sources or DMI as observed in lactating cows fed diets containing both silage and high levels of concentrate (Tyrrell and Moe, 1975). Dry matter digestibility was 3.3 percentage units greater for BMRM than ISOM. The observed 9.2 percentage unit increase in NDF digestibility for BMRM compared with ISOM would account for a 4.1 percentage unit increase in DM digestibility. Thus, differences in DM digestibility between the two corn silage varieties at maintenance energy intake were primarily due to increases in fiber digestibility of the bm3 corn silage.

Lignification of fiber is accounted for in the digestibility estimation equation of Weiss et al. (1992). With that equation, the estimated digestibility at maintenance of the isogenic and bm3 corn silages were 69.5 and 72.0%, respectively. The observed TDN values of the isogenic and bm3 silages were 72.1 and 74.8%, respectively (Table 8). With the equation of Weiss et al. (1992, estimated TDN values for both isogenic and bm3 corn silages were 2.6 and 2.8 percentage units lower, respectively, than the observed values. Thus, the expected difference in TDN between the two silages was accounted for, but the observed TDN was underestimated slightly by the Weiss (1992) equation. Using this method, chemical analysis that incorporates lignin content was successful in estimating the differences in maintenance TDN values between the isogenic and bm3 corn silages.

In experiment 2 using dry cows, measured energy values for DE, ME, and NE$_L$ were 0.12, 0.15, and 0.12 Mcal/kg of DM greater, respectively, for BMRM than ISOM (Table 8). Dry cow diets contained 98% corn si-

lage, and, therefore, the measured energy values would closely approximate the energy value of feeding corn silage alone. Reference energy values of well-eared corn silage in the NRC (1989), estimated at maintenance energy intake, were 3.09 and 2.67 Mcal/kg of DM for DE and ME, respectively, compared with the measured values of 3.20 and 2.62 for the isogenic corn silage. Comparing measured energy values of BMRM diets to NRC values of corn silage, BMRM diets had greater DE and ME values, due in part to the greater digestibility of the bm3 corn silage.

Applying digestive efficiency estimates, measured at a maintenance level of feeding, to lactating cow diets fed at several times maintenance results in an overestimation of digestibility (Tyrrell and Moe, 1975). The associative effects of feeding multiple feedstuffs and DMI impact the accuracy of estimating digestive efficiencies related to dietary constituents (Tyrrell and Moe, 1975). Thus, there was a need to measure the effects of feeding bm3 corn silage on digestive efficiency in lactating dairy cows fed mixed diets at high intake.

Digestibility of NDF and cellulose were 4 percentage units lower in cows fed BMR compared with BMRR (Table 5). However, DM digestibility was not affected by ad libitum feed intake in cows fed the bm3 corn silage based diets (BMR vs. BMRR). In a review, Tyrrell and Moe (1975) observed that most of the decreases in DM digestibility due to intake were associated with decreases in fiber digestibility. Increased digestibility of other components appeared to counteract the measured decrease in NDF digestibility observed in cows fed BMR.

Despite increases in DM and OM digestibility, diets containing bm3 corn silage fed to lactating and maintenance cows resulted in lower CP digestibility compared with those diets containing isogenic corn silage. It is unclear whether the decreased apparent digestibility of CP is associated with decreased N availability due to corn silage variety or increased fecal N excretion associated with microbial N assimilation during hindgut fermentation (NRC, 1985). Cows fed diets containing bm3 corn silage in experiments 1 and 2, exhibited either a decrease or a tendency for a decrease in digested N and urinary N excretion compared with cows fed diets containing isogenic corn silage (Table 7). This reduction in digested and urinary N can not be completely accounted for by differences in N intake and retained N. Although it is unclear whether the current reductions in digested and urinary N are due to decreased nitrogen availability or increased OM fermentation in the hindgut, we have recently demonstrated in lactating cows that N availability was similar between the same diets used for experiment 1 (unpublished). Thus, it is likely that the current differences

in the N balance of cows fed bm3 corn silage diets are due to increased hindgut fermentation (NRC, 1985) and the subsequent increase in microbial N associated with a more digestible feedstuff (Barnes et al., 1971; Lechtenberg et al., 1972, 1974). Increased fiber digestibility and differences in the fibrous fractions would likely increase hindgut fermentation and microbial N production in cows fed bm3 corn silage diets compared with cows fed isogenic corn silage (NRC, 1985). An increase in microbial N would therefore result in a lower apparent digestibility of CP.

Milk production was increased by 2.4 kg/d in BMR cows versus BMRR cows (Table 4). Of the 8.8 Mcal/d increase in ME intake observed in cows fed BMR (Table 7), 1.6 Mcal/d of ME were partitioned toward milk energy, 4.0 Mcal/d of ME were partitioned toward tissue energy, and 3.2 Mcal/d of ME were lost as heat production. The increased concentration of ME associated with feeding bm3 corn silage diets ad libitum resulted in the majority of additional ME being partitioned toward tissue energy gain and not milk energy. Metabolizable energy partitioning can be affected by milk production, stage of lactation, and limitations due to other nutrients in the diet. For example, increases in milk production could be limited by the protein concentration of the diet, and affect the partitioning of excess metabolizable energy. However, the protein content in these diets were approximately 20% CP, which is well above NRC requirements (1989) for cows of this production and stage of lactation. This suggests that protein was not a limiting factor. Cows in progressively later stages of lactation partition less ME toward milk production as production decreases. Additional ME available to these cows would likely result in greater tissue accretion rather than milk production. Cows began the 12-wk experiment in early lactation, but were well into midlactation by the end of the experiment, possibly limiting the milk production potential and leading to tissue energy gain. Consistent with this data, dairy cattle in early lactation fed bm3 corn silage-based diets were in positive energy balance, leading to slight gains in BW, despite increased milk production (Oba and Allen, 1999).

In experiment 1 with lactating dairy cows, there were no statistical differences in DE, ME, and NE_L concentrations in the diet among ISO, BMRR, and BMR dietary treatments (Table 8). However, there was a tendency for increased DE, ME, and NE_L in the diets containing bm3 corn silage. This may in part be because corn silage made up only 60% of the diet DM, thus the effect of bm3 was diluted in the mixed diet. Another factor possibly contributing to the lack of differences in energy values is the level of intake and possible associative effects of other dietary ingredients. Therefore, mea-suring the energy value of corn silage or any single feedstuff within a diet is subject to error (Andrew et al., 1991; Tyrrell and Moe, 1972; Wilkerson et al., 1997).

Estimates of DE, ME, and NE_L values for the corn silage in the three experimental diets are presented in Table 9. For the calculation of these energy values, NRC values for dietary ingredients were adjusted downward by an additional 4% to reflect that the cows in the current study were eating at 4× maintenance intake rather than 3× maintenance intake assumed by NRC (1989). Estimated NE_L values (NRC, 1989) for the corn silage fraction of the ISO, BMRR, and BMR diets were respectively, 1.43, 1.45, and 1.52 Mcal/kg of dietary DM. The average of the two bm3 corn silages was 1.49, which was 0.05 Mcal/kg higher than the isogenic corn silage. The differences in the NE_L values between the isogenic and bm3 corn silages when fed to lactating cows, was not as great as the differences observed in dry cows fed at maintenance (Table 8). However, it is equivocal whether the variation in the differences in the calculated NE_L values for the two silages between the lactating and dry cow experiments is due to DMI or reflects systematic errors associated with estimating the NE_L value of a single dietary component in diets containing single or multiple energy components.

In summary, bm3 corn silage provided greater amounts of energy when fed to dry cows at maintenance, principally due to the increased fiber digestibility associated with the bm3 corn silage. However, the estimated differences in energy values of bm3 corn silage were smaller when fed to lactating cows. This suggests that increases in milk production observed when feeding bm3 corn silage are primarily driven by increases in DMI.

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